Name ____ AP Chemistry

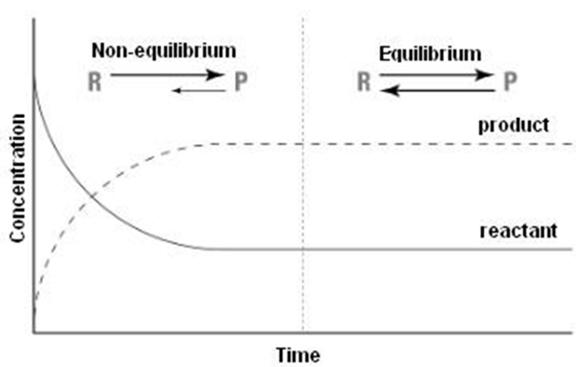
Dynamic Equilibrium, Equilibrium Constant, & Reaction Quotient

Dynamic Equilibrium

When there is a continuous exchange of items between one population and another, the system will reach dynamic equilibrium. In chemical reactions, an equilibrium state can be recognized when the number or particles or concentration of each of the two populations (reactants and products) remains constant, but there is evidence that individual atoms or molecules are still exchanging between the two populations. In other words, chemical equilibrium is:

Characteristics of chemical equilibrium:

- Forward rate of a reaction equals the reverse rate of a reaction in reversible reactions
- The ratio of product concentrations to reactant concentrations is constant



Equilibrium Constant & Reaction Quotient

A numerical relationship between the concentrations of the reactants and products can be determined by calculating the equilibrium constant (K). This constant measures the ratio of the products concentrations to reactant concentrations. For a generic reaction:

$$aA + bB \leftrightarrow cC + dD$$

$$K = \frac{\qquad}{\qquad}$$

- K = equilibrium constant (no units)
- [A] = concentration of reactant or product (M)
- ^{a} = stoichiometric coefficients from balanced chemical equaton

This expression is known as the law of mass action. Only certain reactants and products are included in the equilibrium constant:

Example #1

Write the law of mass action (i.e. the equilibrium expression) for the following reaction:

$$4\ NH_3\ (g) + 7\ O_2\ (g) \leftrightarrow 4\ NO_2\ (g) + 6\ H_2O\ (g)$$

The value of the equilibrium constant measures the extent to which a reaction occurs. If K is larger than 1 (K>1), the concentrations of the products are greater than the concentrations of the reactants. If K is less than 1 (K<1), the concentrations of the reactants are greater than the concentrations of the products; the reaction hardly proceeds towards completion.

When reactants and products are mixed together, the reaction will not always be at equilibrium. If you compare the reaction quotient to the equilibrium constant, you can tell if the reaction is at equilibrium. The reaction quotient (Q) is determined in the same manner as the equilibrium constant, except it uses the initial concentrations of the reactants and products instead of equilibrium concentrations. To compare Q to K,

- $Q = K \rightarrow$
- $Q > K \rightarrow$
- $Q < K \rightarrow$

Example #2

For the synthesis of ammonia at 500°C, the equilibrium constant is 6.0×10^{-2}. Predict if the following cases are at equilibrium and if they are not, which direction will they shift to reach equilibrium:

(a) $[NH_3]_0 = 1.0 \times 10^{-3}$ M, $[N_2]_0 = 1.0 \times 10^{-5}$ M, $[H_2]_0 = 2.0 \times 10^{-3}$ M

(b) $[NH_3]_0 = 2.00 \times 10^{-4}$ M, $[N_2]_0 = 1.50 \times 10^{-5}$ M, $[H_2]_0 = 3.54 \times 10^{-1}$ M

Problems

1) Write equilibrium constant expressions (K) for the following reactions:
   (a) CS_2 (g) + 4 H_2 (g) ↔ CH_4 (g) + 2 H_2S (g)
   (b) 2 H_2O_2 (g) ↔ 2 H_2O (g) + O_2 (g)
   (c) Cl_2 (g) + 2 Br^- (aq) ↔ Br_2 (l) + 2 Cl^- (aq)
   (d) Ca^{2+} (aq) + CO_3^{2-} (aq) ↔ $CaCO_3$ (s)

2) At 1123 K, methane (CH_4) and hydrogen sulfide (H_2S) gases react to form carbon disulfide and hydrogen gases. At equilibrium the concentrations of methane, hydrogen sulfide, carbon disulfide, and hydrogen gas are 0.00142 M, 6.14×10^{-4} M, 0.00266 M, and 0.00943 M, respectively.
   (a) Write a balanced equation for the formation of one mole of carbon disulfide gas.

   (b) Calculate K for the reaction at 1123 K.

3) When nitrogen oxide gas and bromine gas with partial pressure of 1.577 atm and 0.427 atm, respectively, are sealed in a one-liter flask at 77°C, the following equilibrium is established:

$$2\ NO\ (g) + Br_2\ (g) \leftrightarrow 2\ NOBr\ (g)$$

Given that the equilibrium partial pressure of NOBr at 77°C is 0.624 atm, calculate K for the reaction at 77°C.

4) A gaseous reaction mixture contains 0.30 atm SO_2, 0.16 atm Cl_2, and 0.50 atm SO_2Cl_2 in a 2.0 L container. K = 0.011 for the equilibrium system

$$SO_2Cl_2\ (g) \leftrightarrow SO_2\ (g) + Cl_2\ (g)$$

(a) Is the system at equilibrium?
(b) If not, in which direction will the system move to reach equilibrium?

5) Ammonium carbamate solid ($NH_4CO_2NH_2$) decomposes at 313 K into ammonia and carbon dioxide gases. At equilibrium, analysis shows that there are 0.0451 atm of CO_2, 0.0961 atm of ammonia, and 0.159 g of ammonium carbamate.
(a) Write a balanced equation of the decomposition of one mole of $NH_4CO_2NH_2$.

(b) Calculate K at 313 K.

6) For the reaction: 2 NO_2 (g) ↔ 2 NO (g) + O_2 (g), K at a certain temperature is 0.50. Predict the direction in which the system will move to reach equilibrium if one starts with
   (a) P (O_2) = P (NO) = P (NO_2) = 0.10 atm
   (b) P (NO_2) = 0.0848 atm, P (NO) = P (O_2) = 0.0116 atm
   (c) P (NO_2) = 0.20 atm, P (O_2) = 0.010 atm, P (NO) = 0.040 atm